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PROPELLER V/STOL AIRCRAFT

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INTRODUCTION

Propeller V/STOL aircraft fit into the aircraft spectrum as transports, utility aircraft, and possibly as counterinsurgency fighters in the 300- to 400-knot speed range.

This paper is a discussion of the state of the art on such propeller V/STOL airplanes - mainly from the standpoint of aerodynamics and stability and control. It is not a complete treatment, but just hits a few high spots. It deals mainly with the tilt-wing type such as that of the XC-142A airplane shown in figure 1. Many of the technical points brought up in the discussion, however, are also applicable to the related deflected-slipstream STOL type such as that of the Breguet 941 STOL airplane shown in figure 2. Most of the research work that has been done on propeller V/STOL aircraft has been done on these two general types. However, a limited amount of work applicable to tilting-propeller aircraft such as the X-19A (shown in fig. 3) has been performed and will be mentioned briefly. Basically, however, because of the small amount of research work that has been done on either the tilt-prop or tandem arrangement features, the state of the art on this type of aircraft is relatively poor.

On the other hand, the state of the art for the tilt-wing and deflected-slipstream types is fairly good. In the cruise flight range, they are essentially conventional propeller airplanes and, as such, they are backed up by a vast background of technology for these normal-forward-flight conditions. And, in the VTOL and STOL operating range fairly extensive research work has been done on this type of aircraft over the past 10 years.

RESEARCH BACKGROUND

The research background in the propeller V/STOL field is indicated in figure 4. It has included flight research with four research aircraft. This work has been mainly on flying qualities, although other areas such as operating problems and vibratory loads have been investigated to a lesser degree. There has also been a considerable amount of free-flight model work. This has consisted mostly of dynamic stability and control research - about 10 different two- and four-propeller

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configurations have been covered. And, finally, there has been a large amount of wind-tunnel research on aerodynamics (and also on stability and control) in which a very large number of complete models and model components have been covered. The research airplanes and free-flight models have demonstrated repeatedly that they can be flown in hovering flight and can make the transition between hovering and normal forward flight in many different configurations. As a result of all this research, most of the aerodynamic and stability and control problems of this type of airplane have been discovered and fairly well defined; and possible cures for the problems, or means of operating the aircraft so as to avoid the problems, have been devised. The remainder of this paper consists mainly of a discussion of some of these problem areas.

PERFORMANCE

Effect of Wing Size in Cruise

One feature that VTOL aircraft might seem to offer is that the wing might be sized for best efficiency in cruise and not have to be made unnecessarily large for conventional take-offs and landings. On second thought, however, it will be realized that historically it has been found that an airplane must have a large wing span if it is to have good all-around efficiency, in other words, if it is to have good multimission capability. However, if you should want to emphasize high-speed performance at low levels at the expense of all other operating conditions, you might want to design for as small a wing as possible. For example, this is what was done with the Thompson Trophy racers of 20 or 30 years ago. We are all familiar with these effects of wing size in the cruise flight range. Let us go on, however, to see what the effect of wing size is in the novel V/STOL range of operation.

Effect of Wing Size in Transition

Figure 5 shows the effect of span on the power required in the transition range for tilt-wing or deflected-slipstream aircraft. The illustration is for the case of a two-propeller airplane and a four-propeller airplane having the same gross weight and the same total propeller disk area. Both airplanes have wing spans equal to the span across the propellers so that the span of the two-propeller airplane is less than that of the four-propeller airplane. Two curves are shown for each configuration. The dotted lines show the ideal power required as calculated from classical induced-drag and momentum relations, and the solid lines show the actual power required as determined from wind-tunnel tests.

These curves show that the airplane with the greater span requires significantly less power at a given speed in the transition range, or that it can fly slower with a given power. This is a fundamental characteristic, and not just a characteristic of the particular configurations

tested, since the result is shown by the ideal curves calculated from basic physical relations.

These results, then, indicate that the large-span wing, which is generally desirable in the cruise condition, offers decided advantages in the transition range in terms of take-off and landing speed and distance for STOL operation, and in terms of minimum safe speed from engine-out considerations. This point on the effect of span is very timely in connection with some of the requirements that have been discussed for a COIN fighter airplane. That is the requirement for short span. These curves show that the price of a short span is greater take-off and landing speeds, and consequently distances.

Comparison of Tilt Wing and Tilt Prop in Transition

These low power-required curves - down near the ideal - can be achieved. But, it is quite easy to get away from the ideal and have a much higher power-required curve in transition. To get these low curves it is necessary to make the wing work effectively. For example, figure 6 shows power-required curves for tilt-propeller and tilt-wing configurations. With the tilt-propeller configuration as presently conceived, the wing is of short span - only out to the propeller nacelles - and small chord. With this type of configuration the power-required curve is much higher than the ideal for an aircraft with an effective span equal to the span across the propellers. This high power required is partly the result of low or negative angles of attack on the wing due to the propeller slipstream and partly due to the fact that most of the lift is being provided by the propellers which are, in effect, two low-aspect-ratio lifting surfaces.

Poor power-required curves can also be obtained with the tilt-wing configuration if the wing is not working effectively - for example, if the wing stalls as shown in figure 7. These power-required curves show simply that the power required is much higher for the wing which stalls in the transition range. The implication of these curves is that the take-off and landing speed and distance would be significantly greater for an airplane with a wing that stalls and that the minimum safe speed from engine-out considerations would be greater.

Figure 6 indicated a marked superiority in terms of power required, and consequently in STOL performance for the tilt-wing configuration. This is true for a general purpose airplane where you can afford to put on enough wing to provide the lift required to avoid stalling. However, if you wish to build an airplane almost exclusively for high speed at low altitude where you cannot afford to put on much wing, a tilt wing would stall much worse than is indicated by this figure, and the tilt-prop configuration might be the better of the two.

FLYING QUALITIES IN TRANSITION

Effect of Wing Stall

Poor performance is one result of wing stall; and, of course, poor flying qualities is another. The effect of wing stall in transition on flying qualities of a tilt-wing V/STOL airplane is shown in figure 8 using results obtained in flight tests of the VZ-2 tilt-wing research airplane. Here in the top figure for the original airplane with a plain tilt wing we show a region of dangerous and unacceptable flying qualities on a plot of rate of climb against airspeed. The behavior of the airplane in this unacceptable region is characterized by the wing-dropping, wallowing motions, and heavy buffeting normally associated with extensive wing stalling. This unacceptable region seriously limits the usefulness of the airplane, because it is in this region of airspeed and rate of descent that the pilot would like to make his approaches.

The two lower sketches show that the region of unacceptable flying qualities has been moved far down into the descent range and the possible operating range of the airplane greatly opened up by the use of conventional high-lift or stall-control devices such as flaps and leading-edge droop. The results for the flap-down condition were obtained from free-flight model tests since the full-scale airplane has not yet been flown in this condition.

Relief of Stall

From figures 7 and 8 it is evident that there is a wing-stall problem in transition and that this stall can be relieved by the use of a wing that is big enough and has enough high-lift devices to produce the lift required without stalling. The question is, can a designer design a wing to be free of stall or the adverse effects of stall? The answer to this question is that there is enough research information on hand to permit the design of a satisfactory wing, provided you are willing to play it safe and put on a little extra chord and flap. But, if you want to design the minimum wing that will do the job, some fairly extensive wind-tunnel tests with a powered model are required.

Stability and Control

This wing-stall problem is one aspect of flying qualities. Another aspect is the general stability and control area. The main results of the NASA research in this area can be summarized simply. There are a number of different kinds of stability and control troubles that it is possible to get into; but research has shown that, by proper design, it is possible to achieve reasonably acceptable stability and control characteristics with tilt-wing and deflected-slipstream aircraft provided

wing stall is avoided. But, at the present stage of the game, it is necessary to work out such problems as the provision of adequate directional stability and adequate control in wind-tunnel tests of each particular design.

GROUND EFFECTS

Flow Pattern in Hovering

The general character of the slipstream flow of multipropeller VTOL aircraft when hovering near the ground is shown in figure 9. The slipstreams of the individual propellers tend to spread out radially along the ground. And, as they meet at the plane of symmetry they tend to flow upward - straight upward at a station between the propellers, and upward at progressively smaller angles ahead of and behind the center of the aircraft. This upward flow along the plane of symmetry of the aircraft creates a very deep region of intense slipstream flow directly ahead of and behind the aircraft which has marked effects on various problems associated with slipstream recirculation as will be explained later in this and other papers. This simple picture of the flow shown in figure 9 explains several of the characteristics obtained in ground effect.

Ground Effect on Lift

The best known ground effect on such aircraft is an increase in lift. The upward flow beneath the fuselage simply creates a positive pressure region there and thereby gives a lift augmentation.

Ground Effect on Flying Qualities

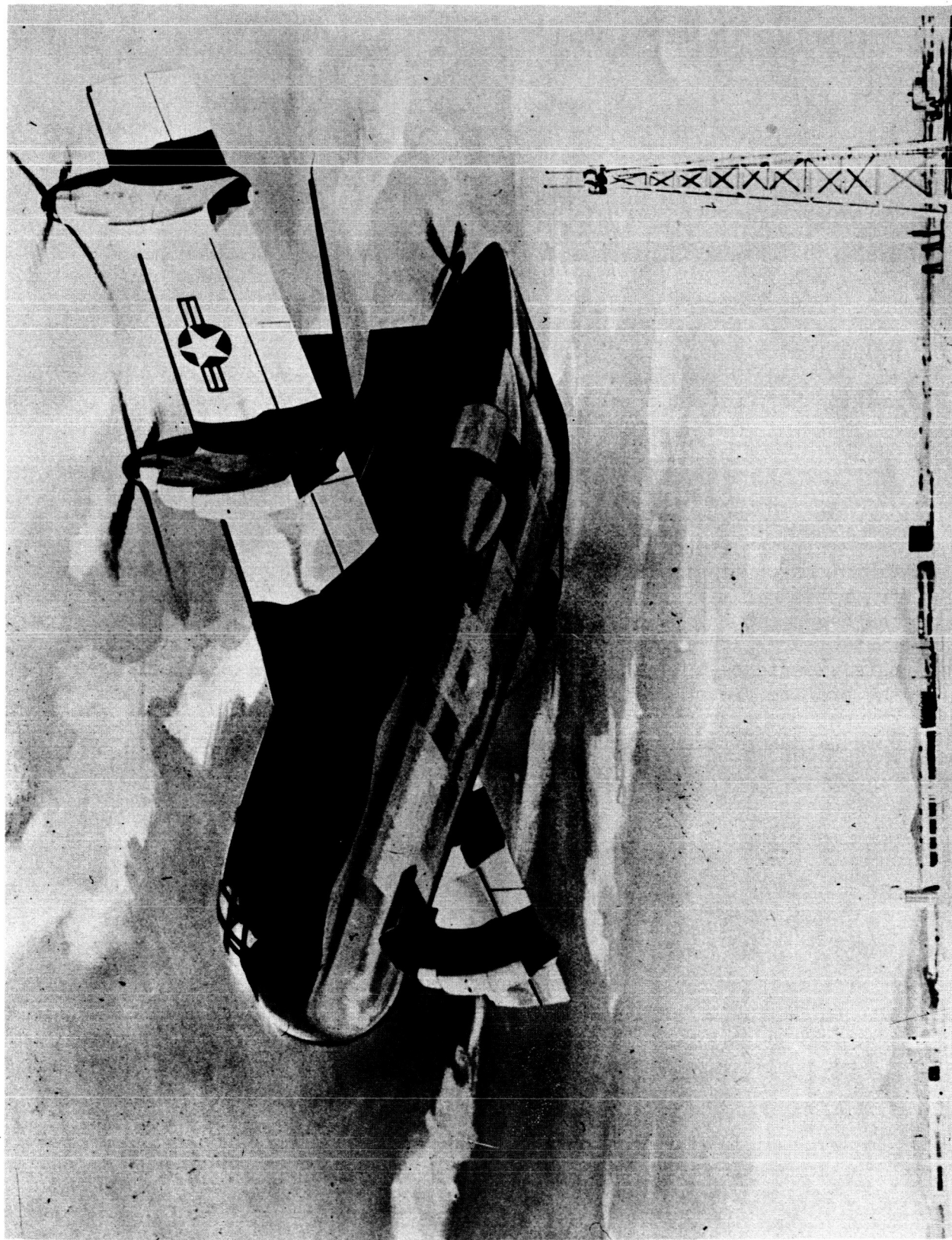
This slipstream flow also affects flying qualities. The flow in the region where the slipstreams intersect along the plane of symmetry is basically not steady and this unsteadiness is increased by movements of the aircraft itself. So, as this unsteady flow moves up alongside the fuselage and recirculates through the propellers it causes large random forces and moments on the aircraft. In other words, it causes the airplane to fly roughly because it is, in effect, in turbulent air. Another cause of unsteadiness might be the unsteady upflow swishing around at the tail of the airplane. Evidence of rough flight due to slipstream recirculation in ground effect is shown in figure 10. This figure shows time histories of the aircraft motions and stick motions of the VZ-2 tilt-wing airplane when hovering in and out of ground effect. The only feature to notice is that the motions of the aircraft are much rougher in ground effect and that the pilot is having to work harder to control the airplane.

The region in which this rough behavior was encountered with the VZ-2 was at heights less than about 15 feet, and the effect persisted at speeds up to about 20 knots as the airplane ran into the deep intense slipstream flow that had been forced out ahead along the plane of symmetry. At forward speeds above about 20 knots the airplane leaves the slipstream flow pattern behind and flies smoothly. These slipstream effects on flying qualities are basic effects and cannot be eliminated. You must simply live with them and operate the aircraft so as to be in this range of low heights and low speeds for as little time as possible.

It would be expected that a four-propeller tandem configuration such as the X-19A would suffer more from this rough flow than a four-propeller tilt-wing configuration because all four propellers are near the unsteady upward flowing slipstream near the center of the aircraft and the upflow will probably be stronger.

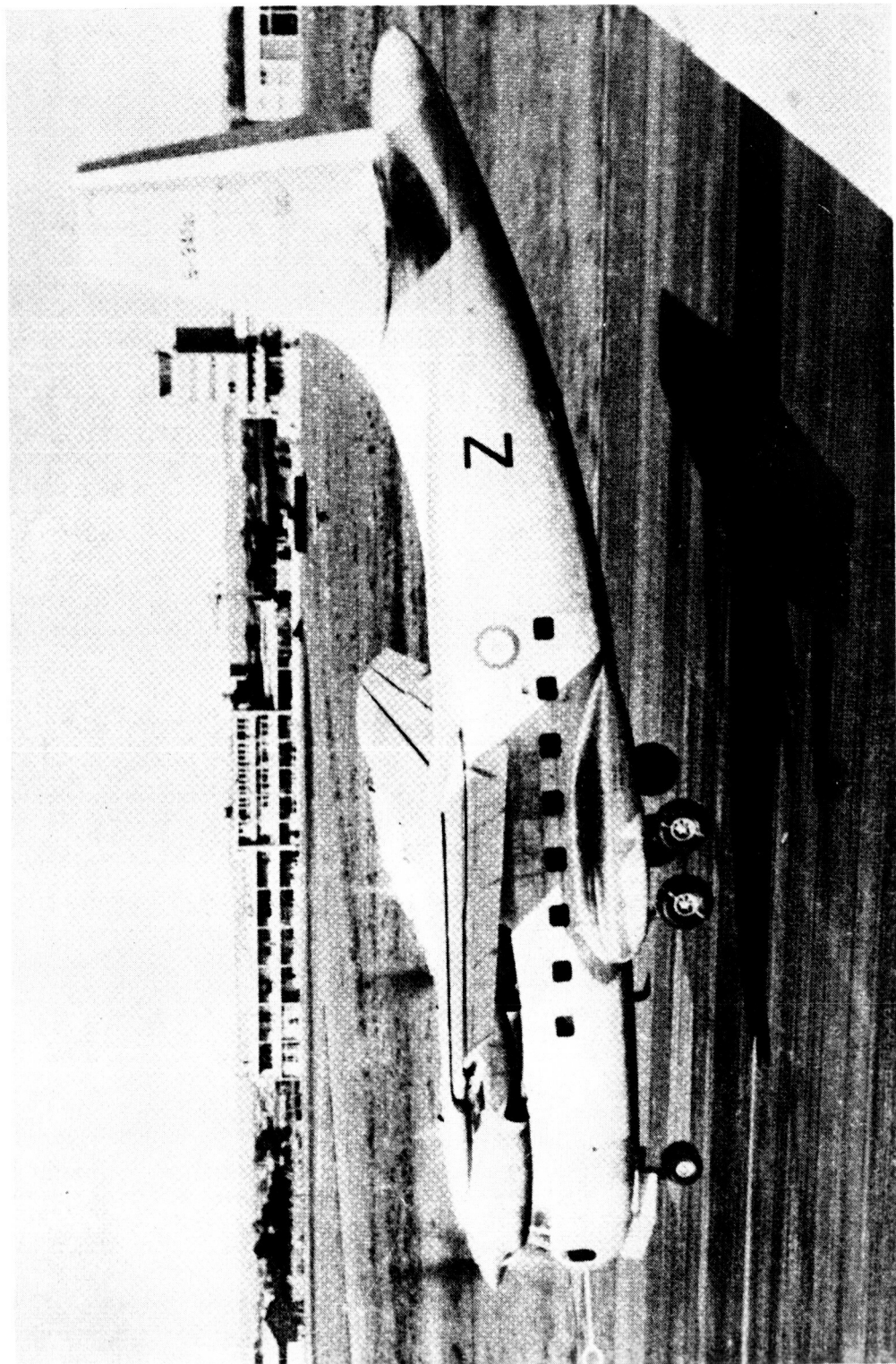
CONCLUSIONS

This paper can best be concluded by reiterating that the propeller V/STOL research aircraft have been flown successfully in several configurations. A great deal of wind-tunnel and free-flight-model research has been done on the hovering and transition ranges of flight for the tilt-wing and deflected-slipstream configurations. The result of all this experience is that for tilt-wing and deflected-slipstream types the problem areas are well defined, the general types of solutions to use on the problems have been discovered, and the development of operational aircraft of this type is well within the state of the art.



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Figure 1.- XC-142A.



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Figure 2.- Breguet 941.

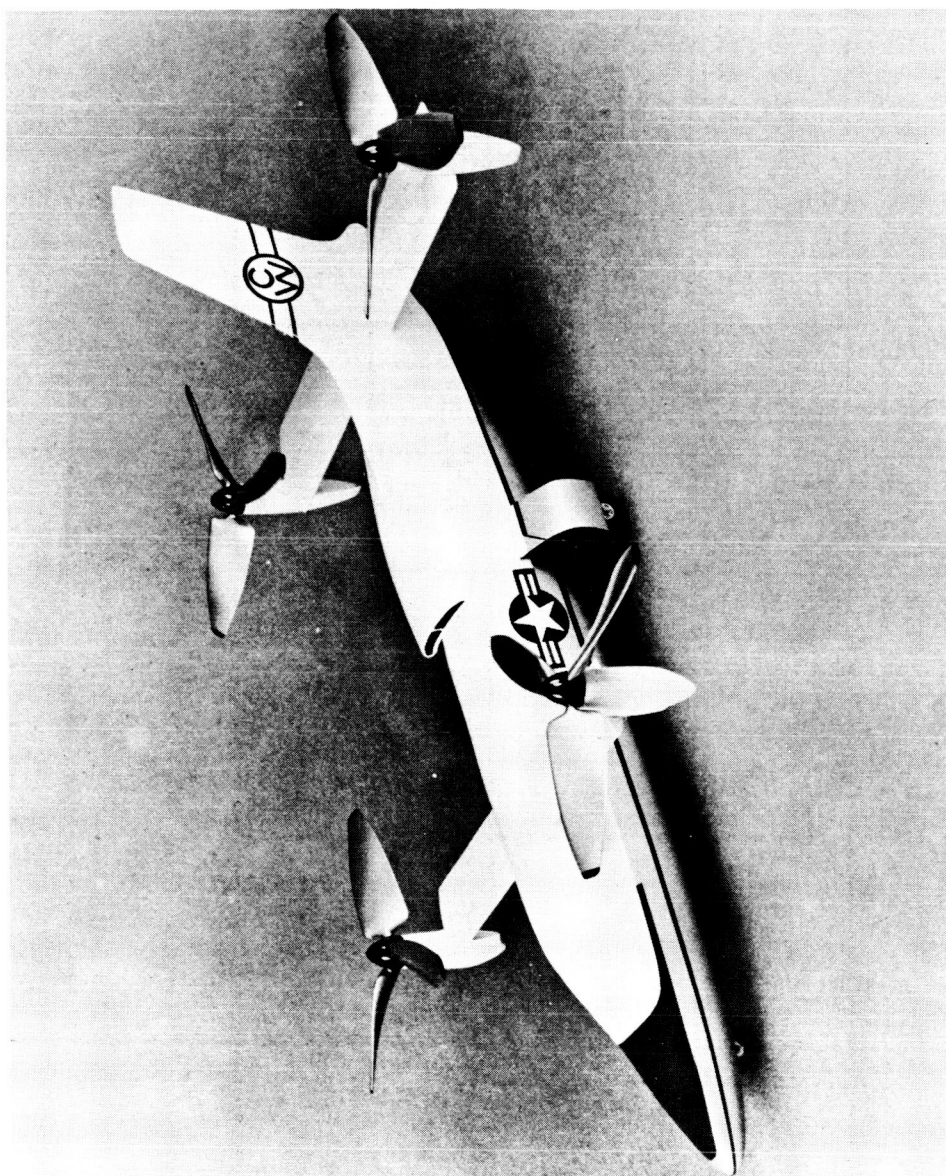
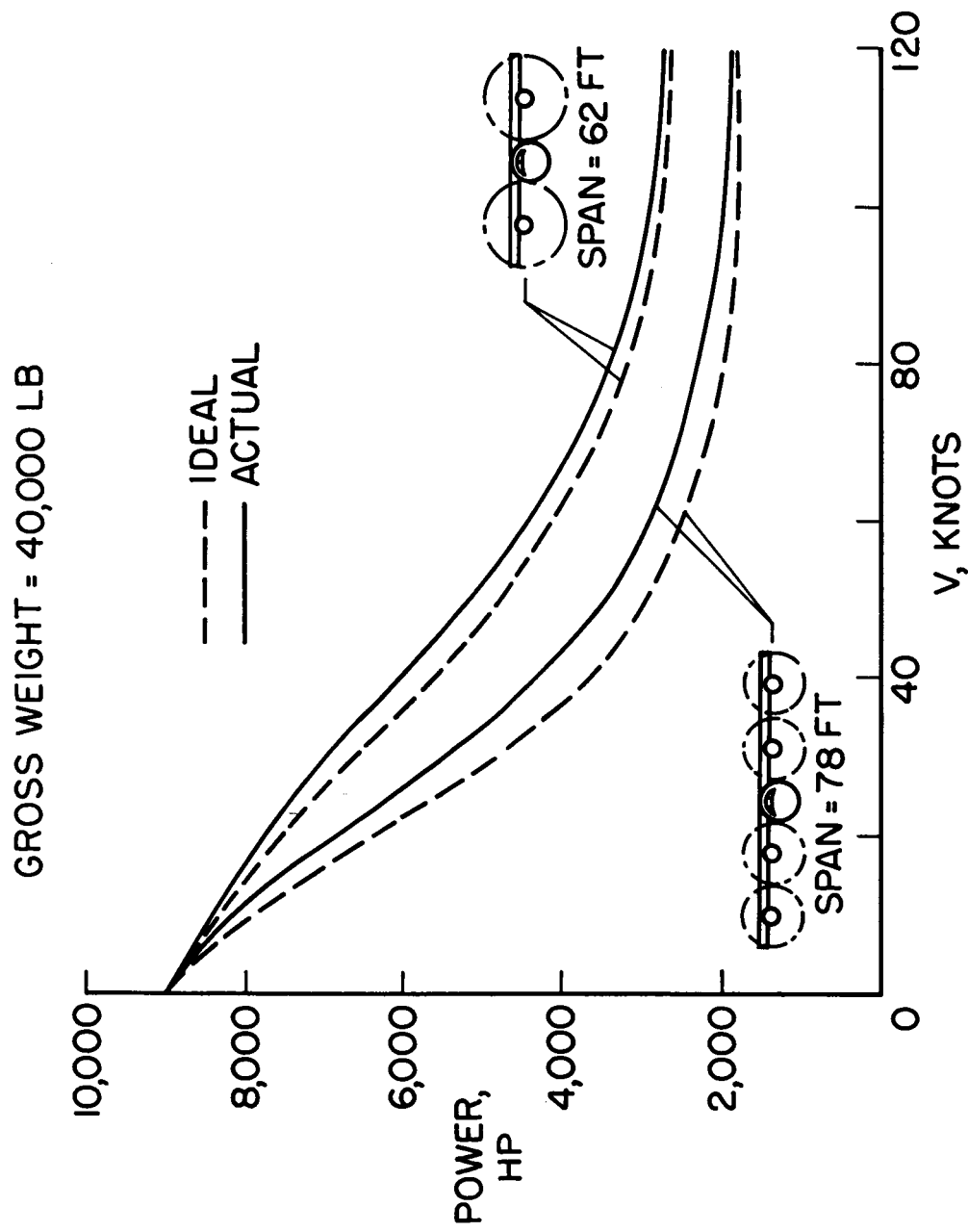


Figure 3.- X-19A.

TYPE OF RESEARCH	PRINCIPAL RESEARCH AREA	COVERAGE
FLIGHT	FLYING QUALITIES	FOUR RESEARCH AIRCRAFT (MAINLY VZ-2 AND VZ-3)
FREE FLIGHT MODEL	STABILITY AND CONTROL	TEN CONFIGURATIONS (BOTH 2- AND 4-PROP)
WIND TUNNEL	AERODYNAMICS	MANY CONFIGURATIONS AND COMPONENTS

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Figure 4.- Research background in propeller V/STOL field.



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Figure 5.- Effect of span or power required in transition.

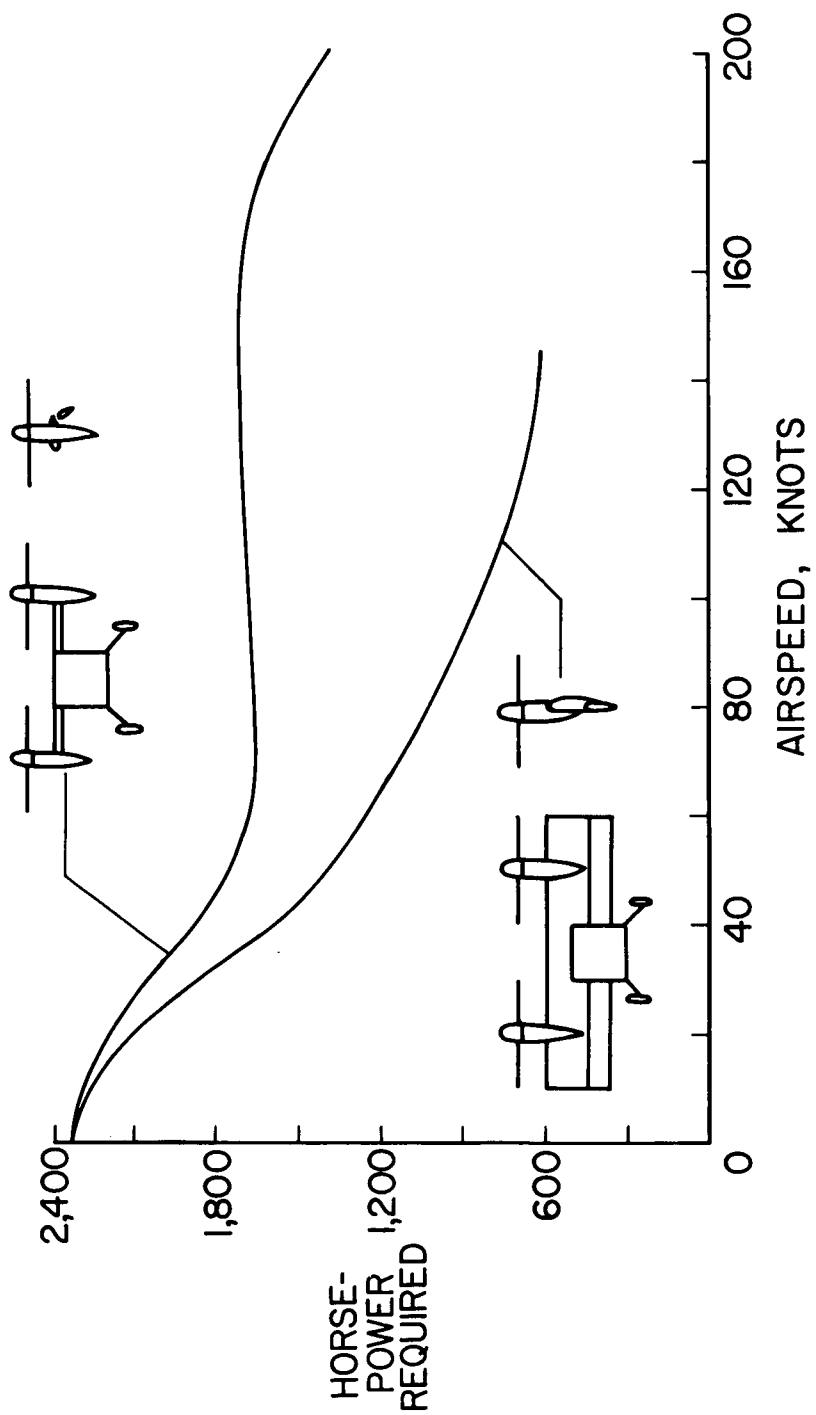
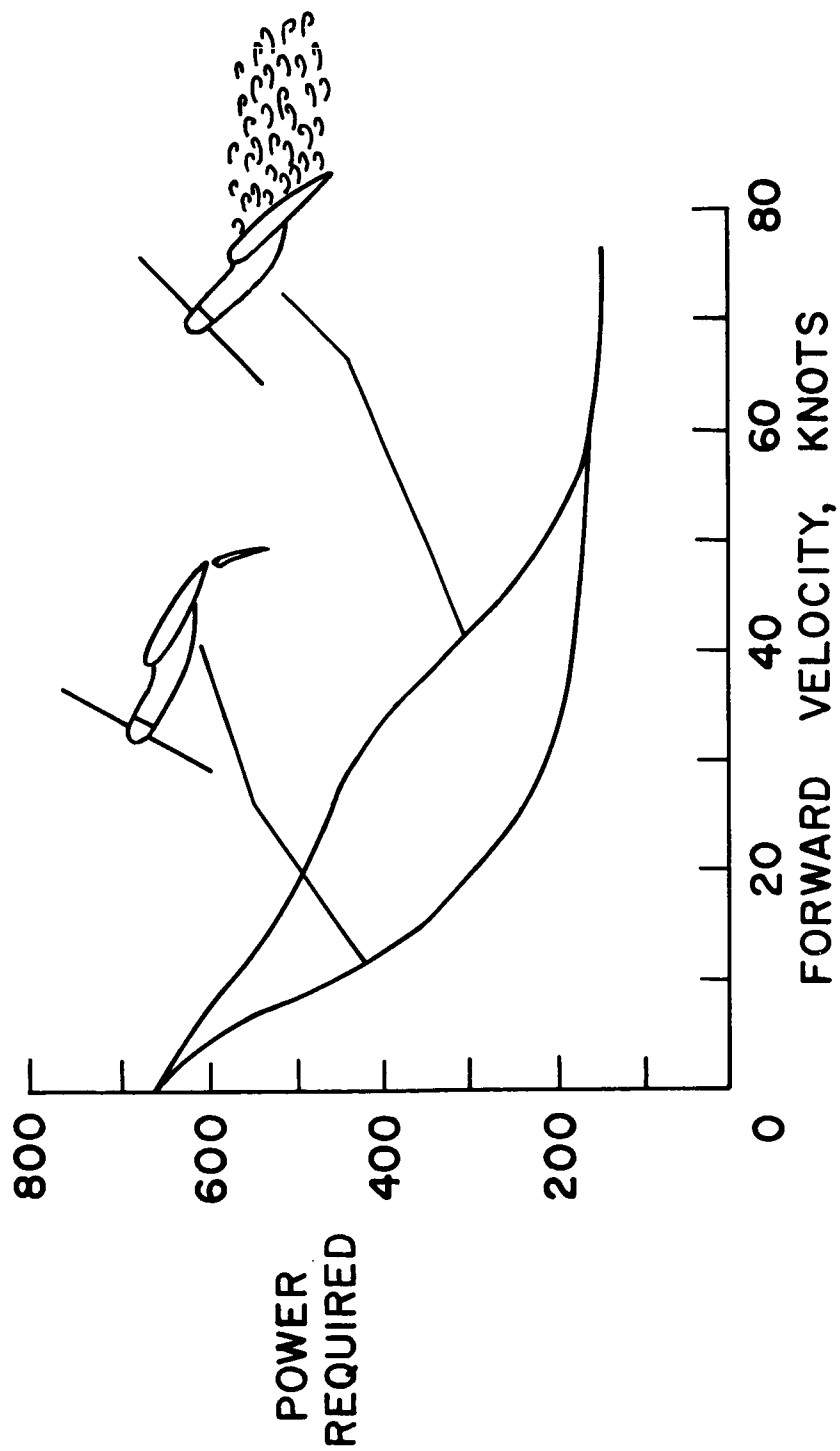


Figure 6.- Comparison of tilt-prop and tilt-wing types.



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Figure 7.- Effect of stall on power required in transition.

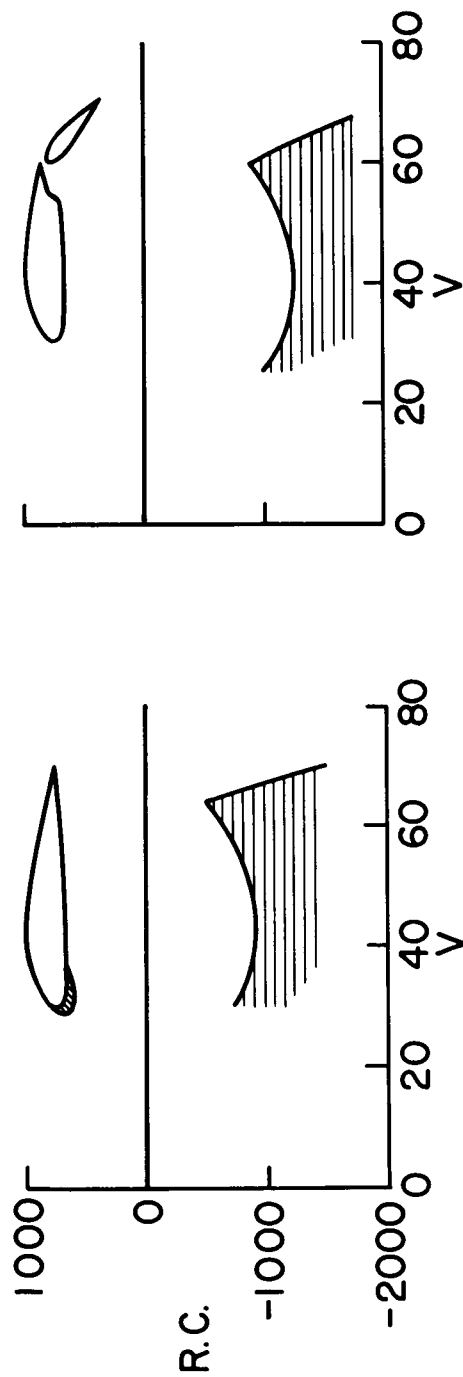
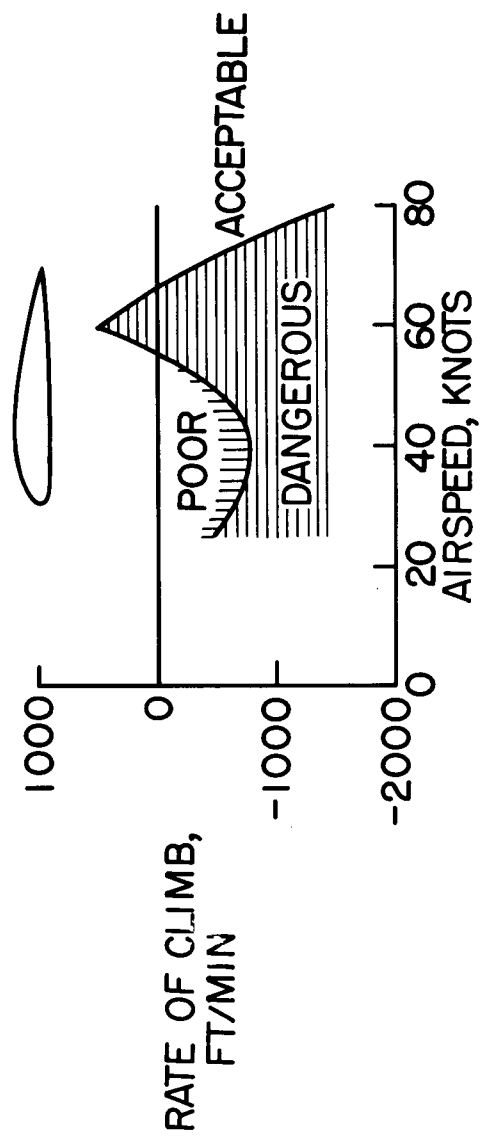
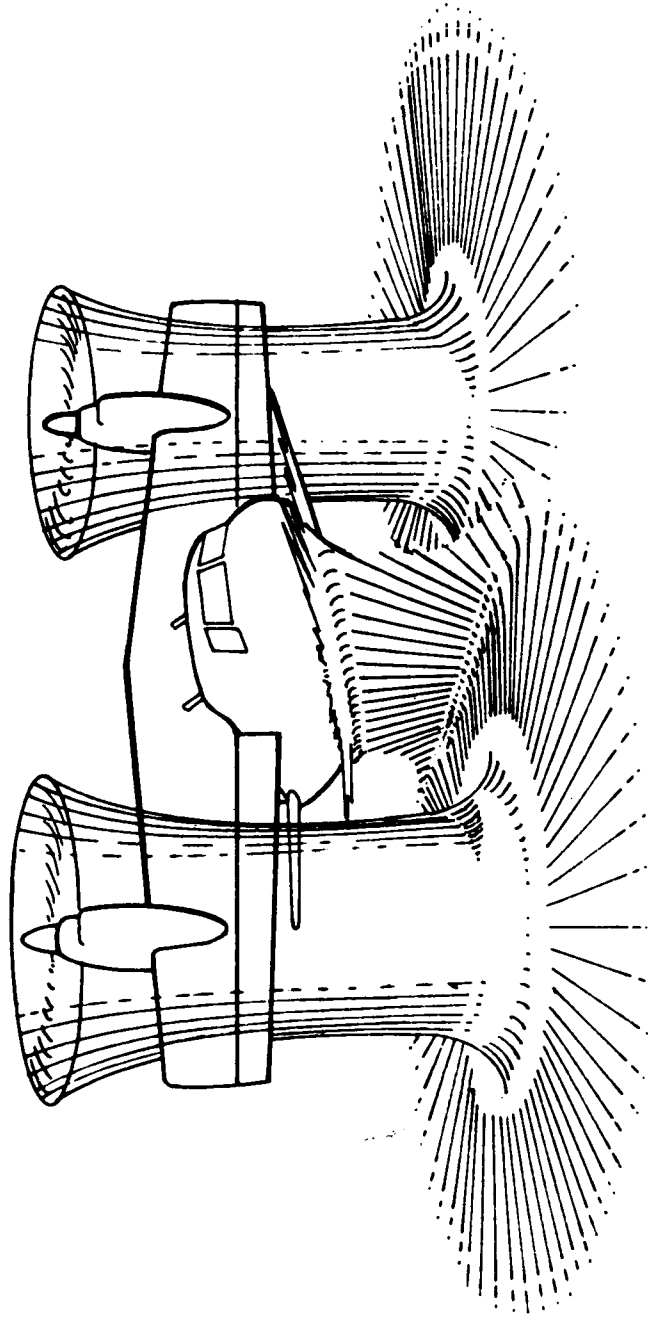


Figure 8.- Effect of stall on flying qualities of VZ-2 in transition.



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Figure 9.- Effect of ground on slipstream flow pattern.

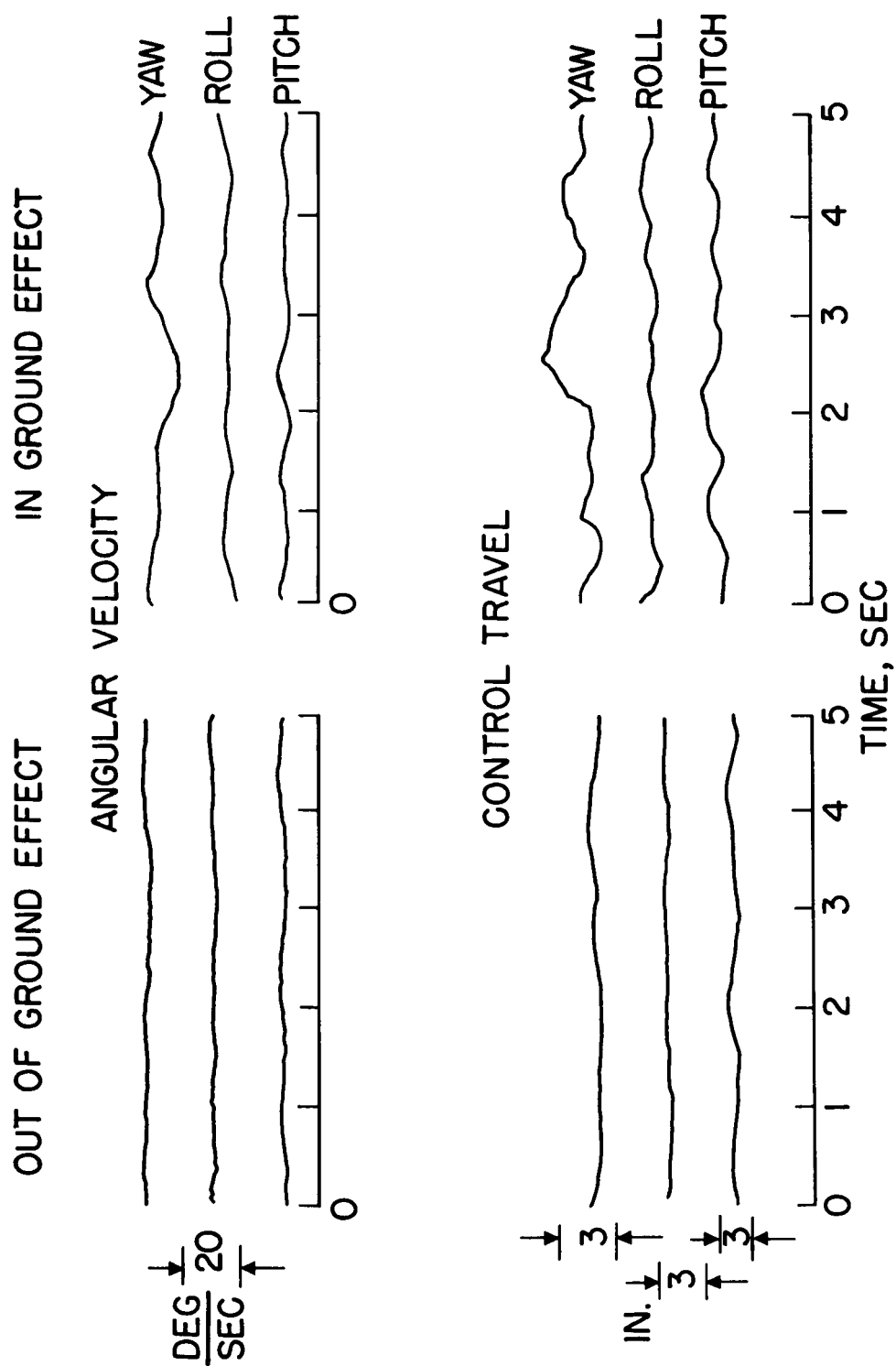


Figure 10.- Effect of ground on aircraft motions.

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